



Astrobee: A New Tool for ISS Operations

Maria Bualat, Trey Smith, Terrence Fong,
Ernest Smith, DW Wheeler,
The Astrobee Team
NASA Ames Research Center
SpaceOps: May 29, 2018



May 29, 2018

Astrobee - SpaceOps 2013

2





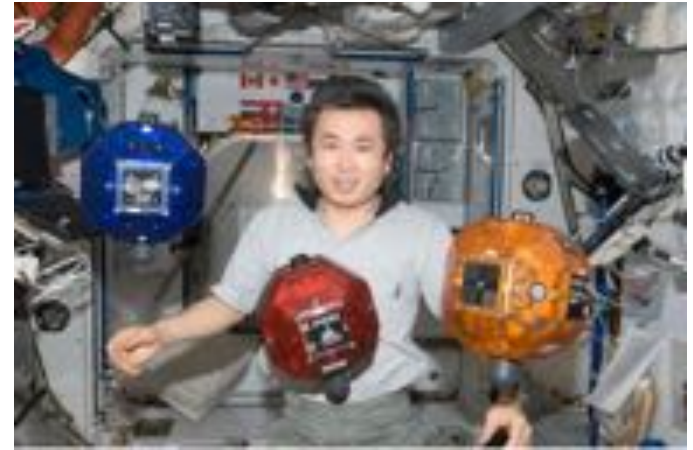


PSA



Current IVA Free Flyers

- SPHERES (NASA) – launched 2006
 - Highly successful research platform used for many guest science experiments
 - Astrobee will replace SPHERES, managed by the same facility team
- Int-Ball (JAXA) – launched 2017
 - Successful experiment in building an IVA free flyer with a rapid development cycle (18 months)
 - Small size (15 cm diameter) enabled by JAXA's miniaturized all-in-one CPU / IMU / 3-axis reaction wheel module
 - Joint activities between Int-Ball and Astrobee may be possible
- CIMON (DLR) – to launch later this year
 - Enable research on AI for human-robot interaction
 - International cooperation – CIMON will share from the pool of batteries that Astrobee qualified for ISS



SPHERES



Int-Ball



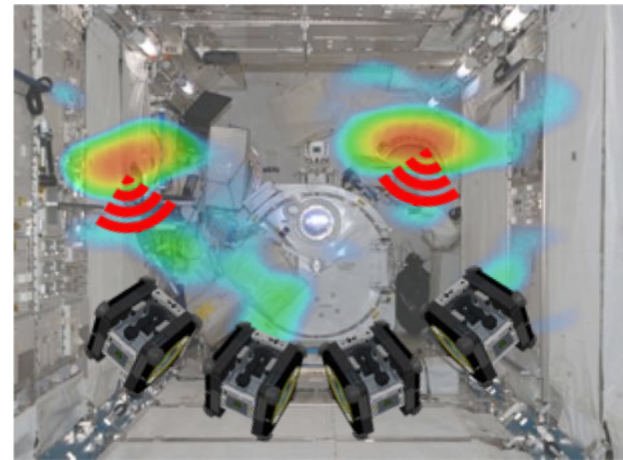
Project Objectives

- Provide a microgravity robotic research facility in the ISS US Orbital Segment (USOS), which will replace the existing SPHERES facility
- Provide remotely operated mobile camera views of the ISS USOS to enhance the situation awareness of mission control
- Perform mobile sensor tasks in the ISS USOS

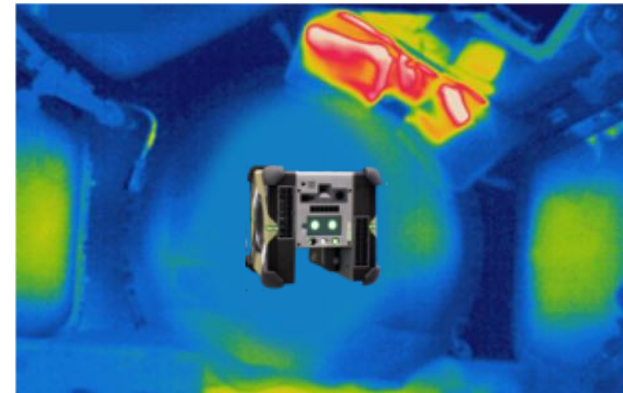


Sensing on the ISS

- Monitor the environment
 - Ensure crew health and safety
 - Maintain vehicle health and longevity
 - Sound levels, radiation, air quality
- Automate logistics
 - Increase efficiency of on-orbit operations
 - RFID localization
- Currently collected by fixed location sensors or by crew-conducted sensor surveys



Localizing signal sources by analyzing RSS spatial variation (e.g. RFID, acoustics)



Habitat thermal mapping

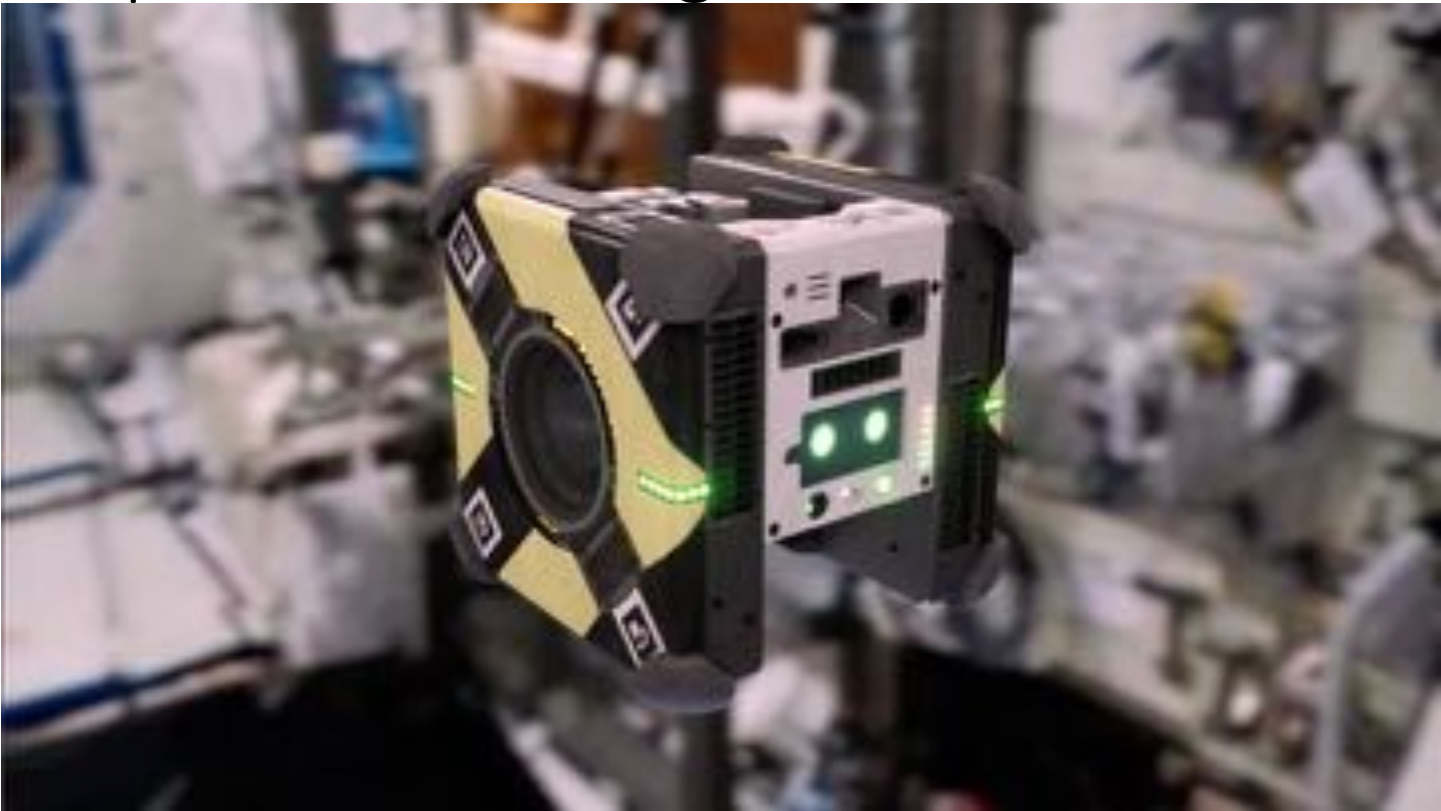


Basic Conops

- When an Astrobee is idle, it charges in its dock
- Astrobees can execute complex plans with full autonomy and no astronauts present
 - Including undock, traverse multiple modules, return to dock
- However, Astrobees run with ground operator oversight
 - When an anomaly occurs, an Astrobee generally stops and waits for operator intervention
 - It can continue operating during communication outages until it encounters an anomaly
- The operator can always take over and teleoperate
- Astronauts can also be operators, but this is rare (minimize crew time)

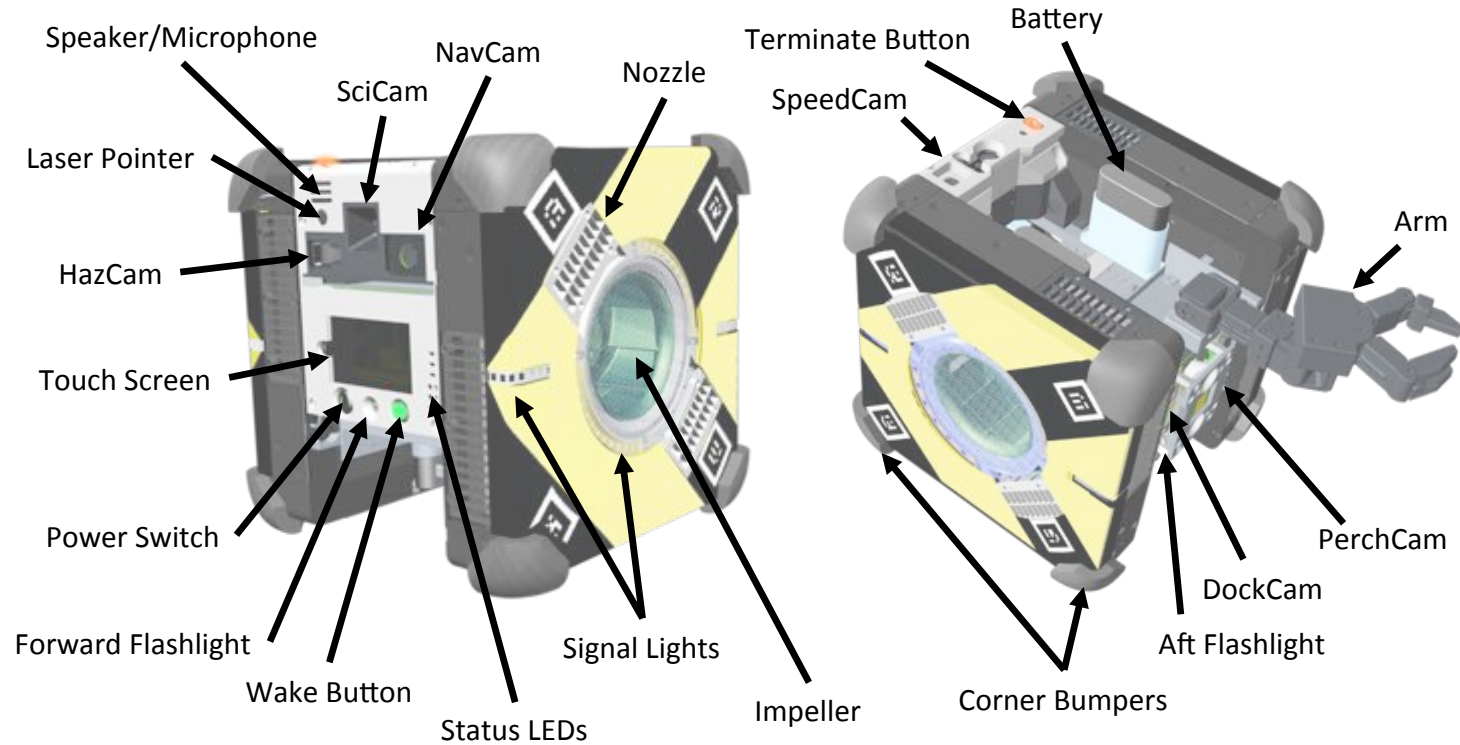


<https://www.nasa.gov/astrobee/videos>





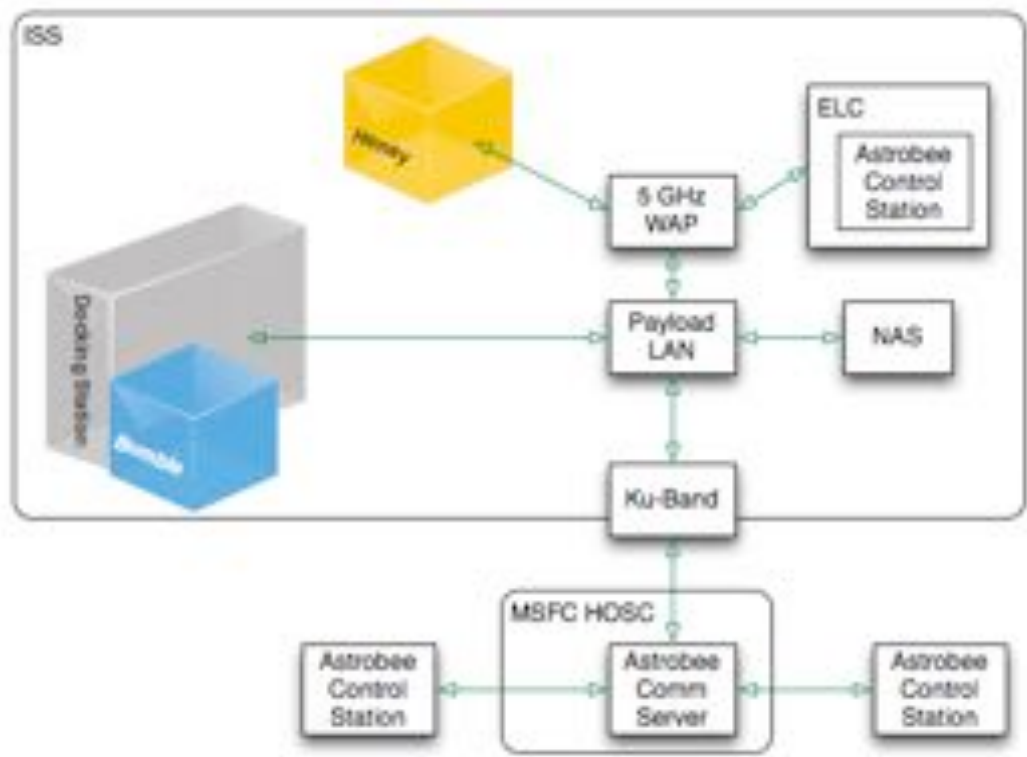
System Description: Sensors & HRI





System Description: Communications

- Communicates through ISS WiFi when flying
- Single telemetry/video stream to ground
- Multiple ground stations can connect through server
- Large file transfers and software updates through Ethernet on the dock



Astrobee communications path



System Description: Position Estimation

- Vision-based navigation
 - Compares features with on-board a priori map
 - Incorporates inertial measurements
- Fiducials used for autonomous docking
 - Requires approximately 1 cm position accuracy
- Visual odometry
 - Robot can continue to navigate where no map features are recognized

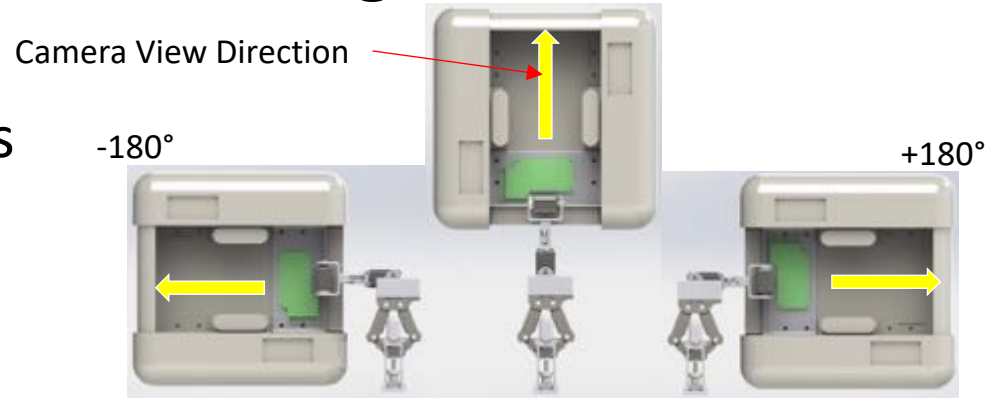


Feature map of the JEM-PM

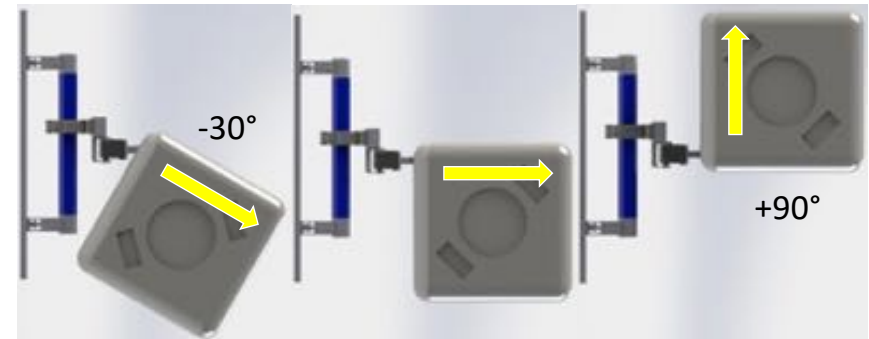


System Description: Perching Arm

- Designed to grasp handrails
- Stows completely in payload bay
- Acts as a pan-tilt unit while perched
- Flexible and back-drivable
- May be perched manually



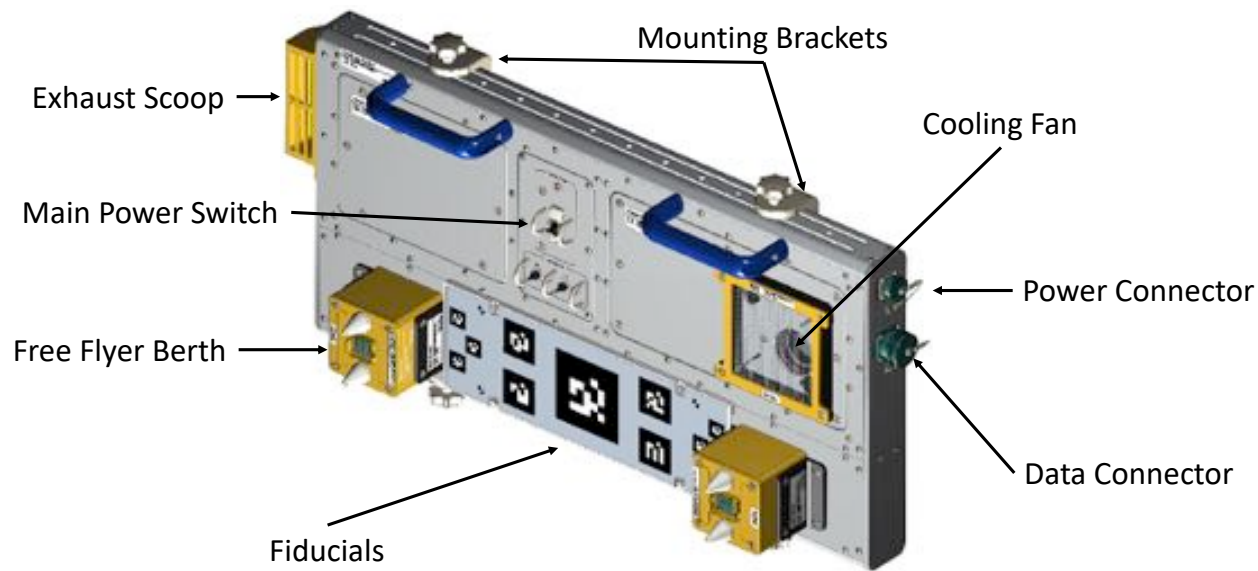
Astrobee Perching Arm pan range



Astrobee Perching Arm tilt range



System Description: Docking Station



- 85 cm x 38 cm x 28 cm
- Berths for 2 free flyers
- Provides power and Ethernet

- Fiducials used for visual servoing to autonomously dock
- Magnets provide retention force



System Description: Ground Data System

- Astrobee Control Station
 - Sortie planning tool
 - Execution monitoring
 - Live telemetry
 - Image and video streams
 - 3D virtual display
 - Supervisory control (run plans or single commands)
 - Typically used by ground operators
- Crew Control Station (used rarely) runs on an EXPRESS Laptop Computer (ELC)
- Server for archiving and distributing Astrobee data
- Suite of engineering tools to support maintenance and software upgrades





Astrobee Control Station

Freeflyer Comm Control DWS@DOW-Windows7-32 Est. Batt 2.39 Docking Station GPS 18Mar17 17:38:44

Health and Status

Operating State	Plan Execution
Mobility State	Flying
Operating Limits	Default_Safeguard
Plan	Survey1
Plan Status	Executing

Initialization **Robot Commanding**

Initialize **Plan Valid**

Local Control Load Run **Power** Skip Group

Description: Survey European Lab and US Lab

Plan
Total Elapsed Time 00:00:25

Plan Step	Duration	Status
Survey1		
0 Station		Complete
0-1 Segment	00:00:46	Complete
1 Station		Complete
1.0 PowerOn/Off		Complete
1.1 Wait	00:00:25	Complete
1.2 PowerOn/Off		Complete
1-2 Segment		
2 Station		
2.0 Wait		
2-3 Segment		
3 Station		
3-4 Segment		
4 Station		
4-5 Segment		
5 Station		
5-6 Segment		
6 Station		

Live Telemetry Live Images Live Video

17:38:08 Freeflyer Run Plan Pending ...



Control Centers

- Astrobee can be operated from almost anywhere
 - Flight controllers at Mission Control Center (JSC)
 - Payload controllers at Payload Operations Integration Center (MSFC)
 - Guest scientists at Multi-Mission Operations Center (ARC) or home institutions
- Provides operators with a mobile camera for improved ground situation awareness during crew activities
 - Optimize viewing angles using the pan/tilt or by relocating Astrobee
- Supervisory control means 100% of operator's attention is not required



Camera Scenario: OSO observes crew maintenance task

- Schedule Astrobee activity
- Use Plan Editor to create 1) a plan that moves Astrobee to crew activity site, and 2) a plan that returns Astrobee to the Dock
- Shortly before crew activity, execute 1st plan
- At start of crew activity, switch to Teleoperate to begin streaming HD video and adjust pan and tilt
- If crew blocks camera view, teleoperate Astrobee to unperch, fly to new handrail, re-perch.
- During LOS, Astrobee will continue to record video
- At conclusion of crew activity, end HD video streaming and execute 2nd plan to return to dock
- Once Astrobee is docked, if desired, downlink recorded video file.



Concept of Astrobee perching for crew activity documentation



Other Operational Considerations

- 3 Astrobees will be on orbit, but only 2 Docking Station berths are available
 - Third free flyer will be stowed and will require crew to charge and install batteries before use
- Multiple free flyer operations
 - Each Astrobee accepts commands from only one Control Station at a time
 - Any Control Station may monitor telemetry from multiple Astrobees
 - Allows operators to watch for interference between multiple Astrobee activities
- ISS operators must schedule use of Astrobee with the Astrobee Facility



Challenges: Safety

- Unique collision hazards: Crew can move faster than Astrobee can move out of the way
- Mitigations
 - Light (low mass, ~10 kg)
 - Slow (max speed 0.5 m/s)
 - Soft (corner bumpers and foam padding)
 - Signal lights/noise when entering hatchway
 - Keep crew aware through operational techniques
 - Daily Plan
 - Daily conferences
 - CapCom calls as needed
- Screens cover intakes
- Grills cover nozzle flaps

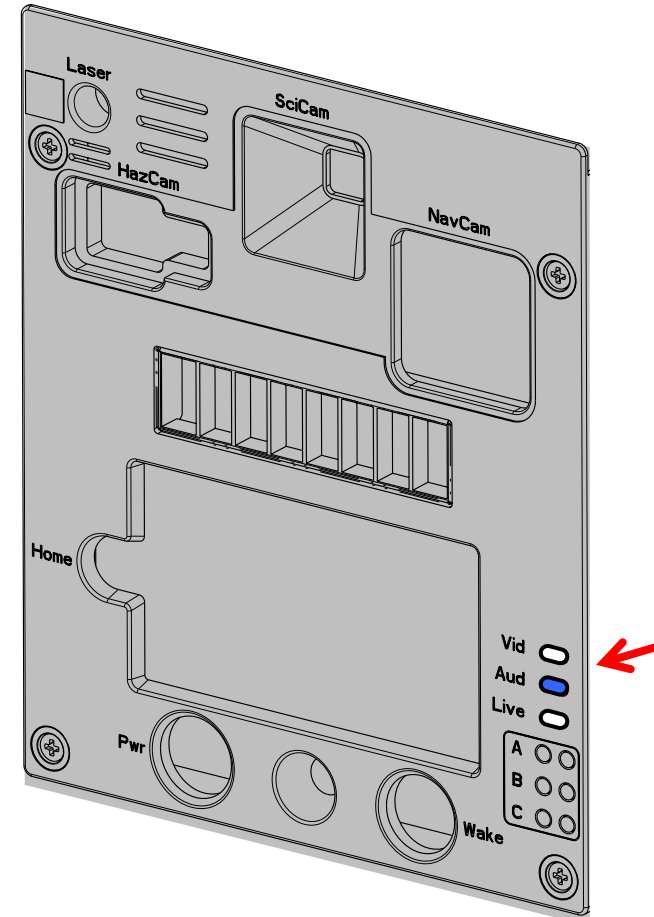


Bumper collision test rig



Challenges: Privacy

- Some cameras always on whenever Astrobee is operating
 - Privacy status LEDs on forward and aft faces indicate when cameras or mic are on and/or streaming
- Crew actually most concerned about live audio
 - In addition to privacy status LEDs, signal lights on left/right Prop Modules will shine blue when mic is on
- Keep-Out Zones (KOZ) can be used to keep Astrobee out of areas where:
 - A crew member is exercising
 - A medical experiment is in progress
 - A sensitive payload is operating
 - An exhaust vent creates fast-moving air that might blow Astrobee off course

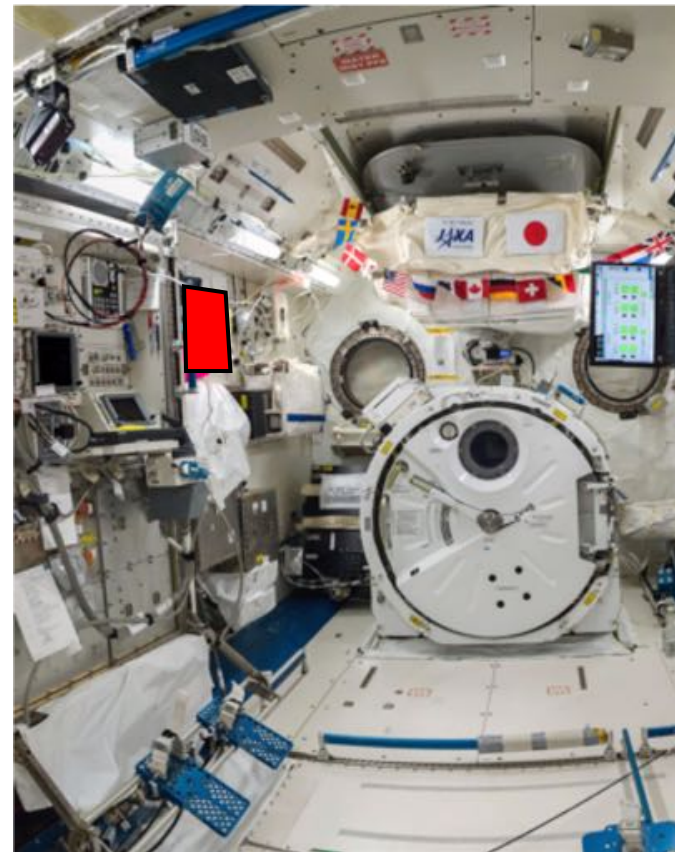


Astrobee forward bezel privacy status LEDs



Challenges: Placement

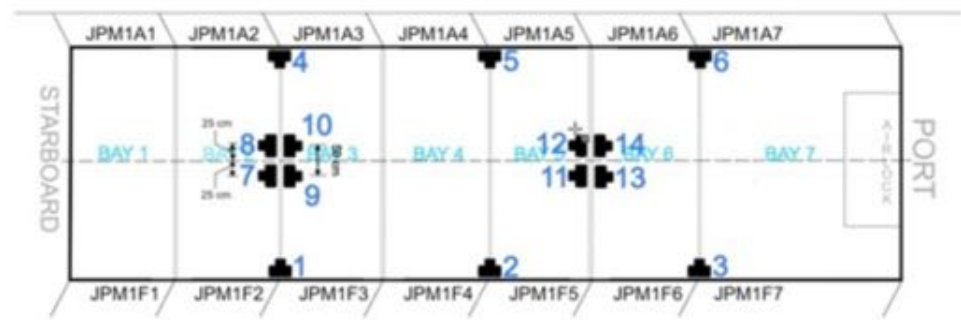
- Difficult to find a “permanent” location for the Docking Station
 - Occupies significant space
 - Want to avoid high traffic areas
 - Anticipated service life until 2024, will last through many changes to ISS
- Lesson learned: expect to be moved, and be flexible
 - Dock design now has many mounting configurations with adjustable brackets, based on both seat track and hook-and-loop
 - Accommodates many possible mounting locations
- Initial location: JAXA has agreed to host the Astrobee dock in the JEM-Pressurized Module Port Endcone, Aft



Initial dock location in red, JPM1A7



Status: First ISS Activity (Pre-Launch)



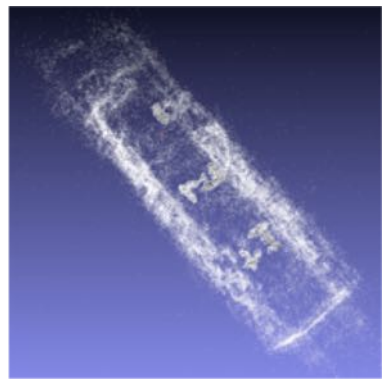
JEM Mapping: Locations of 14 panoramas



ISS CDR Bresnik taking photos,
2017/11/06



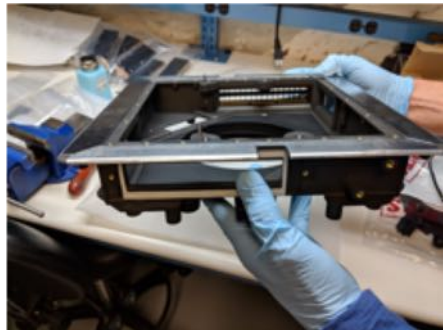
Panorama stitched from 9 photos



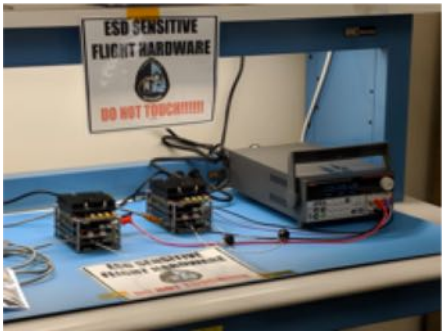
Resulting 3D map of visual
landmarks



Status: Integration in Progress



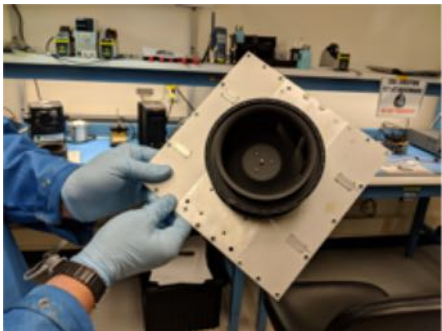
Propulsion Module Plenum



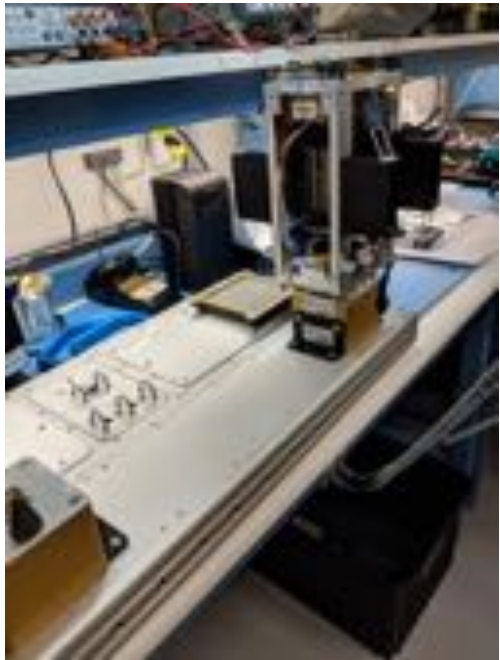
Core Avionics Burn-In



Nozzle Mechanism



Propulsion Impeller

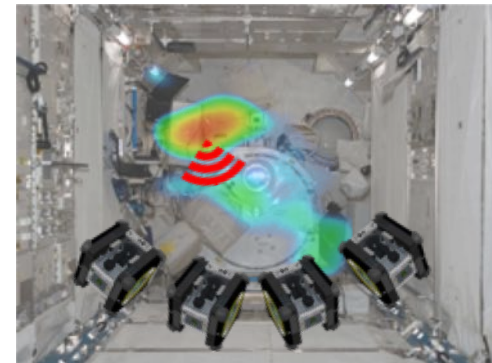


Fit Check – Free Flyer Core with Dock



Future Applications

- Astrobee will help prove out the concept of “Caretaker Robots” for future exploration architectures
- Allows monitoring, maintenance and repair of a facility before and between crews
 - Gateway may be crewed just six weeks per year!
 - Critical need to care for spacecraft when crew are not present
- Inspection functions can include:
 - Spot checks
 - Surveys
 - Automated change detection and trending
 - Localizing problems
- With dexterous robotic manipulation capabilities, future tasks could include:
 - Maintenance
 - Repair
 - Cargo transfer



Isolating faults: Ultrasonic leak detection

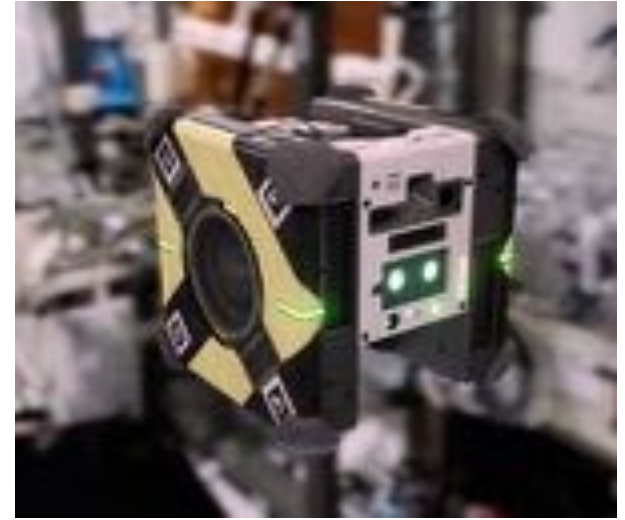


Off-load routine astronaut tasks: Robotic cargo transfer



Conclusion

- Increases efficiency of flight and payload operations
- Improves crew safety
- Mobility caused unique operational challenges
- Launch: November 2018
- Commissioned: mid-2019
- Current status: Integration





Acknowledgments

- Funded by:
 - NASA Game Changing Development Program (Space Technology Mission Directorate)
 - ISS SPHERES Facility (Human Exploration and Operations Mission Directorate)
- Thanks go to:
 - ISS SPHERES Team
 - ISS Payloads Office
 - JSC Flight Operations Directorate
 - ISS Avionics and Software
 - Advanced Exploration Systems Program



Questions?

maria.bualat@nasa.gov